

MONITORING AQUIFER COMPACTION AND LAND SUBSIDENCE DUE TO GROUND-WATER WITHDRAWAL IN THE EL PASO, TEXAS–JUAREZ, CHIHUAHUA, AREA.

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The two-million inhabitants of El Paso, Texas, and Juarez, Chihuahua, create a large demand for water in an arid environment. Much of this demand, about 195,000 acre-ft in 1989, is supplied by ground-water pumpage from the southern Hueco Bolson. The trend of population growth in this area is reflected by a trend in increased ground-water withdrawal, which is expected to continue into the next century.

Land subsidence is one consequence of ground-water withdrawal. Land and Armstrong (1985) reported up to 0.41 ft of land subsidence that occurred between 1967 and 1984 adjacent to the Rio Grande river in El Paso. In 1984, the historic water-level decline in the underlying Hueco Bolson aquifer was about 100 ft in the region of maximum measured subsidence (near Ascarate Lake) and about 150 ft under downtown El Paso. The minor subsidence associated with this water-level decline suggests that preconsolidation stress had not been exceeded by 1984, and compaction was in the elastic range.

The Sierra de Juarez and Franklin Mountains separate the southeast Mesilla Basin from the southern Hueco Bolson (fig. 1). The present Rio Grande flows from the Mesilla Valley into the Hueco Bolson at The Narrows, a topographic low at the southern end of the Franklin Mountains. Until the mid-Pleistocene, however, the ancestral Rio Grande flowed down the east side of the Franklin Mountains, and Bolson deposits aggraded to an elevation equivalent to the surface of the mesa bordering the present Rio Grande Valley. Approximately 0.6 million years ago, the Rio Grande breached the divide at The Narrows and eroded the Rio Grande Valley (John Hawley, New Mexico Bureau of Mines and Mineral Resources, oral commun., 1992). The Rio Grande has since deposited 100 to 200 ft of late Pleistocene and Holocene fluvial sediments in the Rio Grande Valley. The difference between the present elevations in the Rio Grande Valley and bordering mesa areas is typically between 240 and 320 ft and is representative of the net overburden removed by this cycle of erosion and re-aggradation. The resulting change in effective stress can be estimated using the Terzaghi (1925) relation by assuming an average grain density, porosity, and a water-level decline equal to the depth of sediments removed. For an average grain density of 2.7 g/cm³ and an average porosity of 30 percent, an equivalent increase in effective stress would occur with a freshwater hydraulic head decline of about 1.2 times the thickness of eroded overburden. This decline (between 290 and 380 ft) from predevelopment heads is an estimate of preconsolidation stress expressed as a change in water level under confined aquifer conditions. Because freshwater supplies are limited under the Rio Grande Valley, this degree of consolidation suggests that compaction of the Bolson sediments under the Rio Grande Valley may remain in the elastic range for quite some time. The preconsolidation stress threshold for overlying late Pleistocene or Holocene fluvial sediments and Bolson sediments outside the Rio Grande Valley may be significantly lower as it is for analogous sediments elsewhere (Holzer, 1981).

Recognizing the need to quantify the mechanical response of the aquifer to various anthropogenic stresses in the El Paso–Juarez area, the U. S. Geological Survey (USGS), in cooperation with the National Geodetic Survey and the U. S. Section of the International Boundary and Water Commission, began a subsidence monitoring program in 1992. Conventional leveling determined bench-mark elevations to first order, first class accuracy from the Franklin Mountains to the Hueco Mountains, and southeast adjacent to the Rio Grande. The Global Positioning System (GPS) will be used to periodically monitor elevation changes at bench marks along these lines in addition to sites in Mexico (see Ikehara #1, #2, and Pool #1 abstracts for GPS applications in land subsidence investigations).

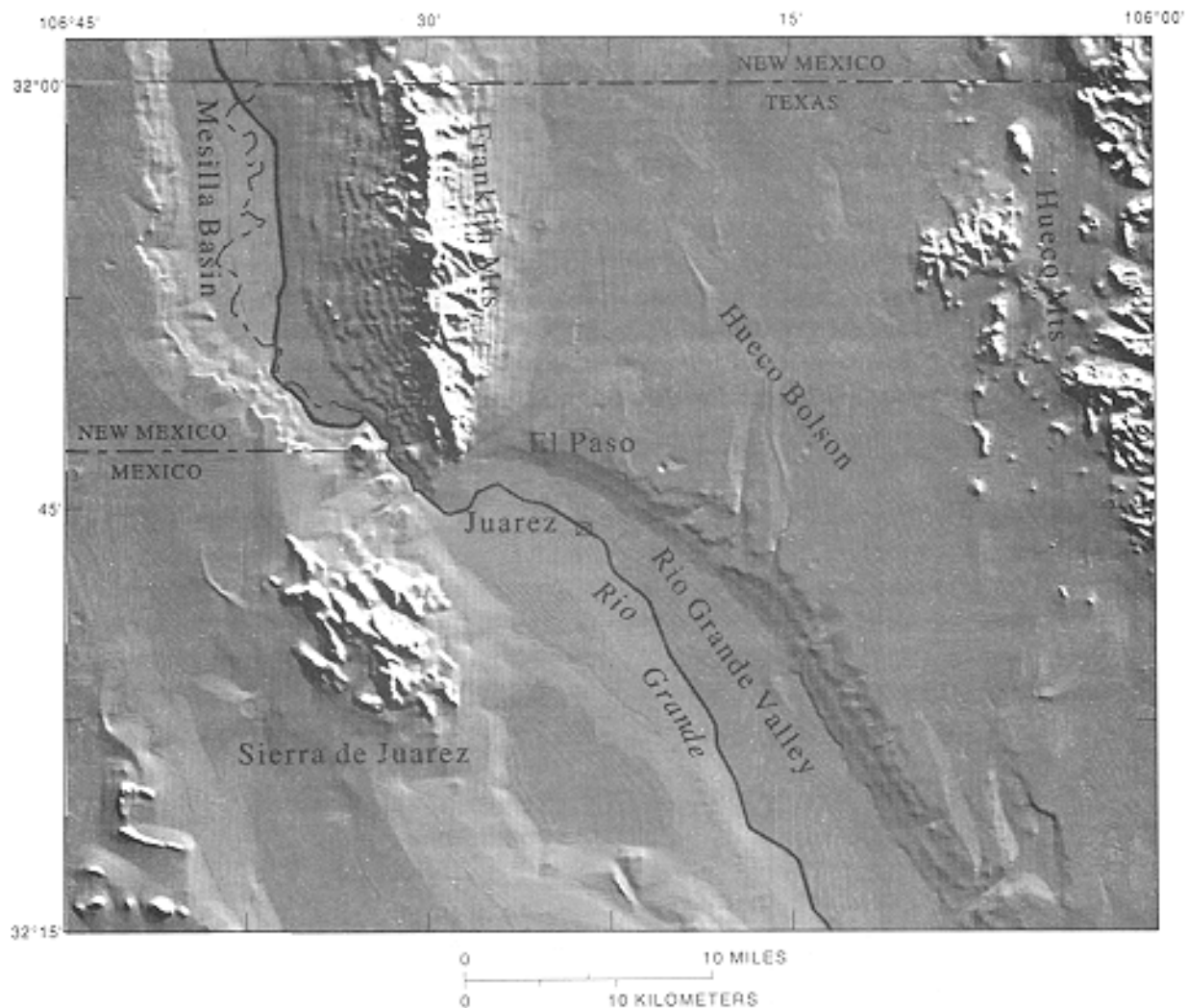


Figure 1. Shaded relief map of southern Hueco Bolson showing extensometer site at $31^{\circ}44'35''\text{N}$, $106^{\circ}23'57''\text{W}$.

The rate of ground-water drawdown accelerated after a major reach of the Rio Grande was lined through El Paso in 1968 (White, 1983). The planned reconstruction and extension of the American canal through southeastern El Paso will decrease leakage from canals and an adjacent unlined reach of the Rio Grande, both of which are components of recharge to the underlying aquifer system. In order to differentiate future compaction in the shallow brackish zone under this reach of the Rio Grande from compaction in the deeper freshwater zone being pumped by the cities of El Paso and Juarez, dual extensometers were installed adjacent to this reach of the river. Because compaction magnitudes are likely to be small at this location and the data will be valuable to infer aquifer storage properties (see Galloway abstract for related discussions), the extensometer installations were designed to achieve maximum sensitivity. The deleterious effects of down-hole friction between the 2-in. extensometer pipe and 6-in. outer casing were minimized by drilling straight holes (deviation less than one degree) and chamfering extensometer pipe couplings. Effects of skin friction between the geologic formation and outer casing were minimized by sealing with a low-friction low-solid bentonite grout. Reverse pile effects were minimized by installing multiple slip joints to accommodate outer casing strain.

Both the USGS and a commercial logging company ran complete suites of borehole geophysical logs to a depth of 1,125 ft. The USGS long and short normal resistivity logs reproduced in figure 2 depict the sand and clay interbeds within the aquifer system. Two sets of three nested piezometers were installed to

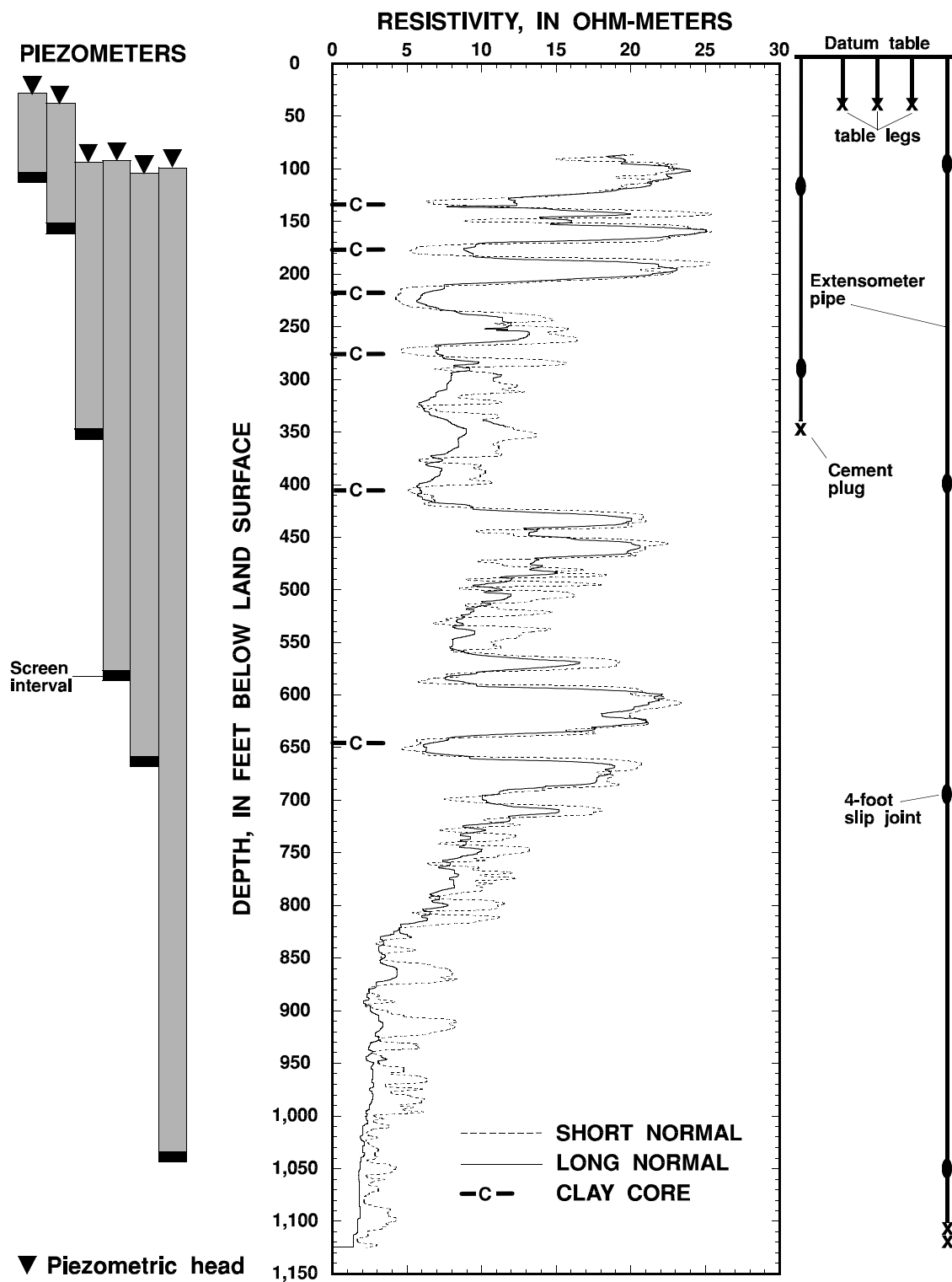


Figure 2. Hydrogeologic summary of extensometer site at the border of El Paso, Texas, and Juarez, Chihuahua.

monitor pore pressure in sandy zones at various depths. A steep downward hydraulic-head gradient is evident across multiple clay interbeds in the brackish zone down to 360 ft. Hydraulic head is lowest in the regional freshwater-producing zone from 350 to 700 ft. The increasingly saline conditions below 720 ft are reflected by decreasing electrical resistivity. The abundance of low permeability clay found below 1,068 ft suggests that significant pore pressure declines probably will not migrate below the base of the deep extensometer at 1,125 ft.

Clay samples 4 in. in diameter and 2 ft long were obtained from six major clay interbeds (fig. 2). X-ray analyses of these samples will determine their mineralogical constituents, and laboratory consolidation testing will yield measurements of elastic and inelastic compressibility, preconsolidation stress, and permeability. These point measurements will be compared to determinations made from the piezometer and extensometer records. Estimates of regional elastic and inelastic compressibilities (see Galloway abstract for related discussions), preconsolidation stresses, and permeabilities, in addition to the leveling data, will be used to refine the predictions of an evolving numerical ground-water flow and subsidence model (for example, see Burbey and Leake abstracts).